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PASSIVE SOLAR CONCEPTS FOR MULTISTORY BUILDINGS*

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ABSTRACT

Multistory buildings long in the east-west direction and short in the north-south direction offer good opportunity for passive solar application. If each unit within the building is designed so that the Solar Savings Fraction is the same, each will respond to the weather the same way and no unit-to-unit heat distribution is needed. A numerical example for Denver is given indicating excellent thermal performance and a several-day thermal response time. Solutions involving distribution of heat from unit to unit are also discussed as well as top-floor and south-wall variations.

1. INTRODUCTION

A common modern building type, a long, thin multistory configuration, is often used for apartment buildings and for other uses. These structures are generally four to seven stories tall, rectangular in both elevation and plan, with an aspect ratio in plan of about 10 to 1. How practical is it to use passive solar heating and cooling strategies in such a building, what types of systems should be used, and what basic principles should be observed? A few specific designs have emerged, primarily for Italy, as described by Los,[1] but these have been specific solutions without much discussion of thermal design principles.

It is clear from the outset that this type of building provides a very favorable potential situation for passive strategies especially if good exterior insulation and infiltration control have been incorporated. Energy requirements are lessened because of party walls. Construction is sometimes brick or clay tile walls; floors are often concrete. The overall geometry is very favorable if the flat side of the building faces south. The central problem that develops is one of balancing the building so that each unit is individually comfortable.

2. SOLUTIONS WITHOUT HEAT TRANSPORT BETWEEN UNITS

If the building is laid out so that each unit has access to the south, it is frequently possible to size the solar collection glazing in direct proportion to the heat requirements of each unit. If this is done, each unit will respond to the climate in the same manner. The thermal design problem is tremendously simplified because each unit can be individually designed without consideration of interactions between units.

The guiding principle is to size the glazing so that the Solar Savings Fraction (SSF) is the same for each unit. If the same passive system or mix of passive systems are used throughout, this is tantamount to making the Load Collector Ratio (LCR) the same for each unit. The LCR is defined as follows:

$$LCR = \frac{\text{Building Net Load Coefficient}}{\text{Collection Area}} .$$

If this process is completed for each unit, the LCR of the entire building will be identical to that for each unit. The building will then respond to the weather and the sun as if it were a single unit. As an example, let us consider an apartment building for Denver, Colorado. In a cold climate such as this, it is appropriate to consider an LCR of about 20 Btu/°F-day-ft^2, whereas in a mild climate an LCR = 30 might be more appropriate to avoid winter overheating. The example is a four-story building with six 784-ft^2 units located side by side for a total of 24 units. The units are 28 ft square by 9 ft high. Opaque exterior walls are insulated to R-19, and all windows are double glazed. On the east, west, and north facades the walls are 90% opaque and 10% window. The ground level is slab on grade with R-12 perimeter insulation, and the flat roof is insulated to R-19. Infiltration is assumed to be 0.6 air changes/hour.

*Work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

The net load coefficient of each apartment unit is shown on the following figure. The net load coefficients are calculated excluding the area of the south-glazed aperture; units are Btu/^{o}F-day.

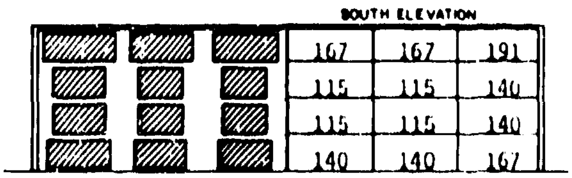
SOUTH ELEVATION

3815	3233	3233	3233	3233	3815
2890	2309	2309	2309	2309	2890
2890	2309	2309	2309	2309	2890
3351	2606	2606	2606	2606	3351

The first thing we notice about these numbers is that the variation is surprisingly small. This is primarily because 56% of the load coefficient of the building as a whole is accounted for by infiltration, and this load is constant unit to unit.

There are six different values of load coefficient. The center eight units are the same, the top four units are the same, etc.

In order to achieve an LCR of 20 in each unit, it would be necessary to divide each load coefficient by 20 to determine the appropriate square footage of glazed area. Because some of the numbers are quite close, it makes sense to merge the original six groups into four groups. When this is done, the required glazing area becomes that shown in the following figure.



On the right side of this figure the required glazing area is given in square feet and on the left side the shaded areas show the required aperture, drawn to scale. The remaining south wall is assumed to be opaque and insulated to R-19; this was accounted for in the calculation of the net load coefficient given previously. An LCR = 20 will give reasonably good performance in Denver assuming a 65 degree day (DD) base. For example, a 12-in. Trombe wall with either night insulation or a selective surface will yield an SSF of 73%, and a direct gain design with a mass surface-to-glazing area ratio of 6 will yield SSF = 59%. (Both systems are double glazed.) These results are from Ref. 2. However, the assumption of a 65^{o}F base temperature is not very realistic for this building. Let us assume that 48 people live in the building and that there is an internal heat-generation rate of 20,000 Btu/day/person due to lights, appliances, and people heat; if, in addition, the total load coefficient of the building is 99,000 Btu/^{o}F-day and the thermostat setting is 70^{o}F, the balance-point temperature for the building is 60.3^{o}F. The degree day value for Denver calculated to this base 4797 DD compared with 6016 for a 65^{o}F base. The resulting SSF, assuming that half of the aperture is direct gain and half is night insulated Trombe wall, is 73%. The resulting auxiliary heating requirement for the entire building is 87 million Btu/year or less than 2 million Btu/unit. At current electric rates (7¢/kWh), costs would average $36/unit/year. The required capacity is about 1 kW/unit.

A second remarkable thermal property of this building is its long-time response characteristic. If we assume that the floors and roof are 6-in. concrete, that the walls are 4-in. concrete, and make allowances for partitions and furniture, the overall heat capacity of the building is 630,000 Btu/^{o}F. The resulting thermal response characteristic (time constant) of the building is 6.5 days. Implications of this long response time are that the building is very stable, that the response to changes in outside conditions will not be felt for 1 or 2 days, and that the time of day when backup heat is used is not very important. Thus, off-peak backup heating would be appropriate.

Layout of individual apartment units must account for the difference in thermal characteristics of the individual spaces created. It is essential that the building be only one apartment thick in the north-south direction. This will allow individual residents to control cross ventilation through their units; this flexibility is essential in the summer. It also means the convective distribution of heat from the south to the north side of the unit can be achieved. Community rooms such as living rooms and kitchens should be located on the south and bedrooms on the north. The south rooms will tend to run 3 or 4 degrees warmer than the north rooms.

The choice of night insulation on an unvented Trombe wall was quite deliberate. If the Trombe wall were vented, it would add heat to the unit during the day when the direct gain is also contributing heat, creating large temperature swings. The time delay of the Trombe wall is a major asset in this situation. Night insulation was chosen, partly because of the improved energy performance and also because it affords a degree of control over solar gain. The night insulation can be put in place all summer to nearly eliminate solar gains and can also be used very effectively in other seasons to regulate the average temperature. The use of backup heat will be so infrequent that by itself it is not an adequate regulating mechanism; consequently, the use of both natural ventilation and Trombe-wall shading will be critical.

3. SOLUTIONS UTILIZING DISTRIBUTION OF HEAT FROM UNIT TO UNIT

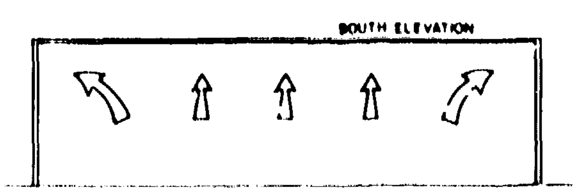
Although the previous discussion has indicated that it is very feasible to achieve an LCR of 20 without counting on distribution of heat from unit to unit, there may be instances where such distribution seems appropriate. For example, if the building were less well insulated, the required aperture on some of the units may be larger than the available south area. It is doubtful, however, that one would ever want to design for LCR less than 20 because of problems that would probably arise in the control of overheating.

The figure below shows a south elevation of the hypothetical building analyzed above. Units marked with a (+) require less energy compared with the average, units marked with a (0) have just the average energy requirement, and units marked with a (-) or (--) require more energy. Note that the units that require more energy are generally located above those with smaller energy requirements, and, thus, distribution of heat can be totally passive.

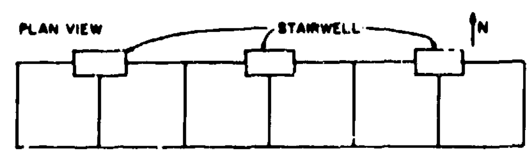
SOUTH ELEVATION

--	-	-	-	-	--
0	+	+	+	+	0
0	+	+	+	+	0
-	0	0	0	0	-

The following figure shows the general way in which heat should flow in the building to balance heat requirements.



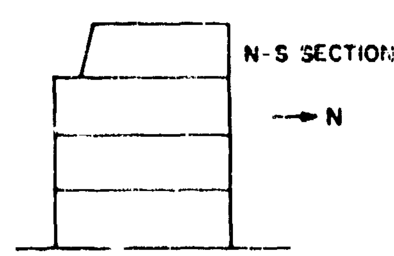
There are many possible ways in which heat could be distributed by natural convection of air. Air might be heated in either air-heating collectors or Trombe-wall spaces and then ducted through insulated ducts to perforated masonry units in the floor or wall of apartments requiring extra heat. The same method could be used for distribution of heat from the south to the north side of each individual unit. The following figure shows how north stairwells could be located to function both as north buffer spaces and as return air passages from the top of the building to the bottom.



The designer must be careful in considering configurations such as this to properly account for fire safety issues that might be raised when vertical air ducts are created in buildings and also to assure that air from one apartment space is not transported into other apartments along with odors and other pollutants.

4 TOP FLOOR VARIATIONS

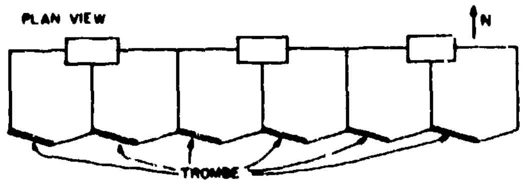
The uppermost floor of the building presents some opportunities for thermal design not available in the lower floors. As we have seen, the heat requirements of the top floor are generally greater, requiring greater collection area. The following figure shows how a sunspace configuration with sloping glazing could be used on the top floor.



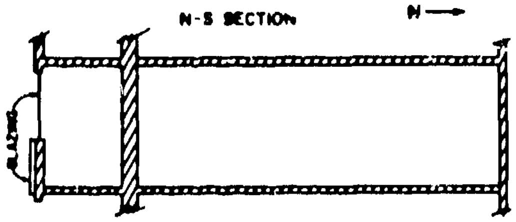
By setting the sunspace glazing back somewhat from the south building edge, an attractive and usable balcony is created that also functions to reflect additional sun into the sunspace. Because of this feature and the sloping glazing, the sunspace effective performance will be greater than that for the lower units. One might make up for the reduced floor area of these units by laying out three double-wide units across the top floor instead of the original six units.

5. SOUTH WALL VARIATIONS

The natural performance characteristics of Trombe walls can be enhanced by an orientation slightly west of true south. This provides for more afternoon-heat pickup and better heat carryover into the evening. Similarly, by orienting direct-gain windows slightly east of true south, one achieves better morning pickup and less tendency for afternoon overheating. The configuration shown below combines these attributes to mutual advantage and will lead to better performance and comfort.



Another very attractive option for this application is a sunspace. The figure below shows a section taken through one apartment unit from north to south showing a sunspace on the south side. The sunspace, in fact, is just a balcony that can be enclosed on the winter.



The glazing may be removed and stored for the summer. The drawing shows that the wall between the sunspace and the house is thicker to provide additional heat storage and thermal isolation. Probably half of this wall would be cut through with doors and windows that are essential for access, light, and daytime distribution of heat to the northern portions of the unit. Active distribution of heat is not essential but may be desirable in certain situations. A Solar Load Ratio (SLR) calculation done for Denver for LCR = 20 for a vertically glazed, semi-enclosed sunspace yields an SSF of 67% and an annual auxiliary heat requirement for the entire building of 106 million Btu.

The sunspace in this configuration has ample heat storage; the floor, side walls, ceiling, and north wall are all effective. The extra thickness of the north wall of the sunspace may not be required. This wall could serve as the major structural spine for the building.

6. CONCLUSIONS

Multistory buildings offer a number of passive solar opportunities and thermal design challenges. The few strategies that have been explored in this paper indicate that excellent performance can be obtained. There obviously are many possible variations, but the designer must be careful to allow a degree of thermal control for the occupants. The thermal design must be done unit by unit and space by space so that each is comfortable when the building requires no backup heat. The long thermal response time of the building is a major asset in achieving this objective.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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2. J. D. Balcomb, R. W. Jones, R. D. McFarland, and W. O. Wray, "Performance Prediction of Passive Solar Heated Buildings by the Solar Load Ratio Method," submitted to the Passive Solar Journal. (LA-UR-82-670)